OPTIMIZING A PROPOSED SOLAR STREETLIGHT DESIGN FOR REMOTE AREAS IN DAVAO REGION

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I. INTRODUCTION

In the Philippine energy sector, Mindanao has been the discussion of every stakeholder as it faced a lot of issues for the past decade, such as energy deficits during the dry season [1], failing electric cooperatives [2], high energy rates, and the lag in electrification [3]. The energy deficit has already been resolved through the commissioning of coal fired power plants across Mindanao. In 2017, 450 MW were added to the grid by these coal plants and an additional 640 MW for 2018 [4]. However, as additional baseload is added, distribution utilities have yet to cover more ground to provide electricity for more residents in Mindanao. In 2017, Mindanao is still at 74% energization status [3].

Moreover, the cost of energy in the electrified areas is expensive. The Philippines has the 5th highest electricity rate in the world [5]. This is despite our vast resources in renewable resources for producing energy. This leads to the lack of competitiveness in the global market when it comes to housing manufacturing facilities. Thus, there is pressure from stakeholders to seek for other means of getting power.

II. SOLAR POWER IN THE PHILIPPINES

In 2016, solar provided only 3.57% of the country's energy despite having a large potential. Being in the tropical region, the Philippines has a solar potential of 5.1 kW/m^2/day [6,7], one of the highest among the ASEAN region. For Mindanao, being much closer to the equator would have a higher potential compared to the national average.

In addition, manufacturing of solar panels have been aggressive in the country. In 2017, Solar Philippines, one of the largest Philippine owned manufacturers has finished its Giga factory in Batangas. It claims to be one of the largest solar panel factories in the world and targets to produce 2.5 million panels a year [8]. In addition, components for solar power generation, such as batteries are also locally made. Motolite, one of the largest battery manufacturers in the Asia-Pacific region is in the Philippines and offer deep cycle batteries for solar projects. The availability and access to resources provide an opportunity for solar power to be a renewable resource of choice for off-grid installations.

III. MICROGRIDS

As a result of the lack of electrification and high cost of energy, households and small businesses have built downscaled systems for producing renewable energy referred to as Microgrids.

Thus, in order to provide further cost savings for these installations, there is a need to implement design optimization apart from only taking into account factors such as capacity, loads, and solar irradiance. This study investigates the optimization of several solar streetlight designs using Homer Energy [9], a microgrid optimization software that integrates technical and economic considerations in designing these systems.

IV. SOLAR STREETLIGHTS

Streetlights are essential during nighttime since they provide light in streets and pathways. They guide drivers and pedestrians by helping them see their way. Having an illuminated path lets them avoid any possible accidents. Most highways in Mindanao do not have streetlights and they often cause accidents. For pedestrians, having adequate lighting lets them continue their business during the dark. Gas powered lamps are typically used to traverse paths, but they pose danger from catching fire.

The use of solar powered streetlights provides lighted pathways without the need of wiring them in the grid. This is advantageous since most highways, especially in rural areas are located far from the grid. However, it is important to note several factors that account for the success of using this technology, such as capacity and storage. Capacity refers to the ability of the solar panel to produce the specified amount of power while storage refers to the ability of the battery to power the load without the presence of the sun. This is because streetlights are used during the night and thus requires the energy to be stored during the day. A system having a capacity that is too low results in the streetlight not being able to be on during the entire night while having a capacity that is too high results in an expensive system with a lot of surplus energy. This consideration also applies to the storage.

Thus, there is a need to optimize the design of the solar streetlight to meet its required function at the least possible cost.

V. METHODOLOGY

a. Proposed Design

In order to carry out the optimization of the design, the requirements of the streetlights are determined. The streetlight will have a height of 7 meters and will have variants of 10-watt, 20-watt, 30-watt LED arrays running on the 12-volt deep cycle battery. Figure 1 shows the sample design and operation of the streetlight.

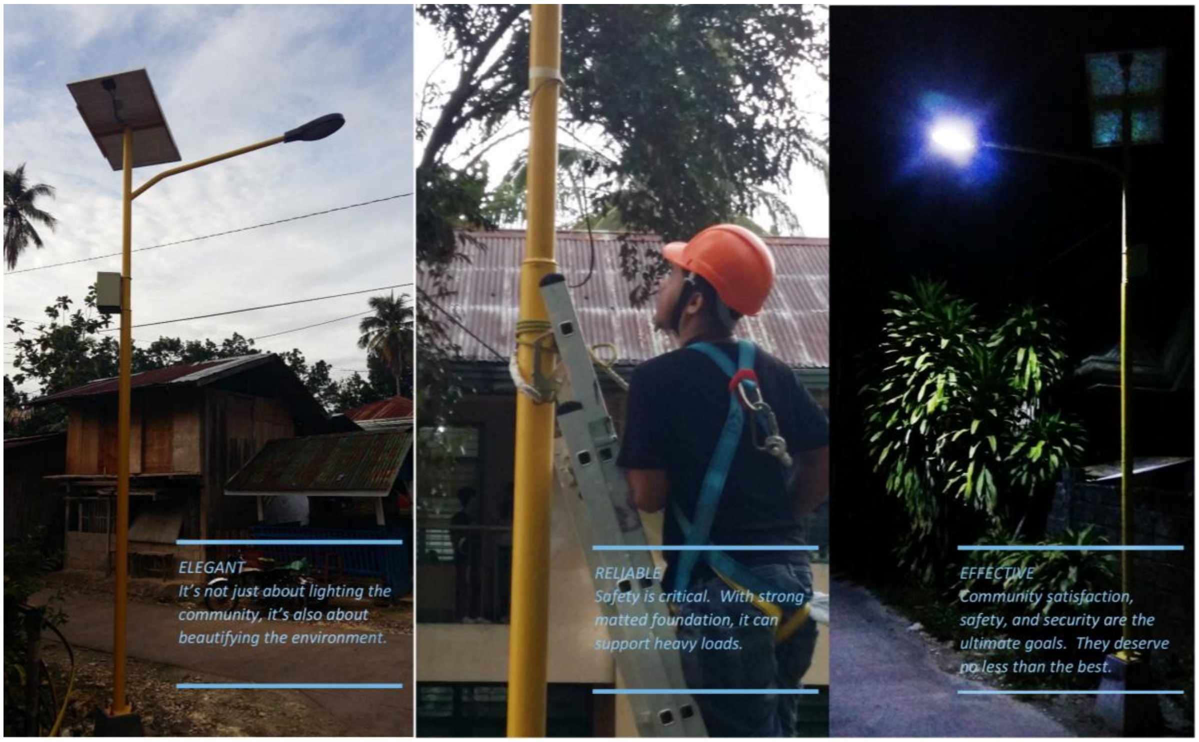

Figure 1. Sample Design and Operation of the Solar Streetlight

The parameters that will be varied in the simulation are the solar panels and batteries. Table 1 and 2 shows the specifications and costs of the solar panels and batteries respectively. The cost of the solar panels are wholesale prices from an overseas supplier while the batteries are purchased from a Motolite distributor.

Table 1. Solar Panel Sizes and Costs.

Output Power (Watts)	Price (USD)
20 W	$ 563.00
50 W	$ 687.00
100 W	$ 785.00

Table 2. Motolite Battery Capacities and Costs.

Capacity (Ah)	Price (USD)
40 Ah	$ 61.00
70 Ah	$ 105.00

100 Ah	$ 121.00

b. Homer Energy

Homer Energy is a microgrid simulation software developed by the National Renewable Energy Laboratory located in Colorado, USA. The study uses the free edition to perform the simulations which provides results such as estimated life of the battery, daily power consumption of the load, setup costs, levelized cost of energy (LCOE), etc. The optimal combination of the panels and batteries will be the one with the lowest LCOE. In the results, other simulated designs will also be discussed to provide further discussion.

VI. RESULTS

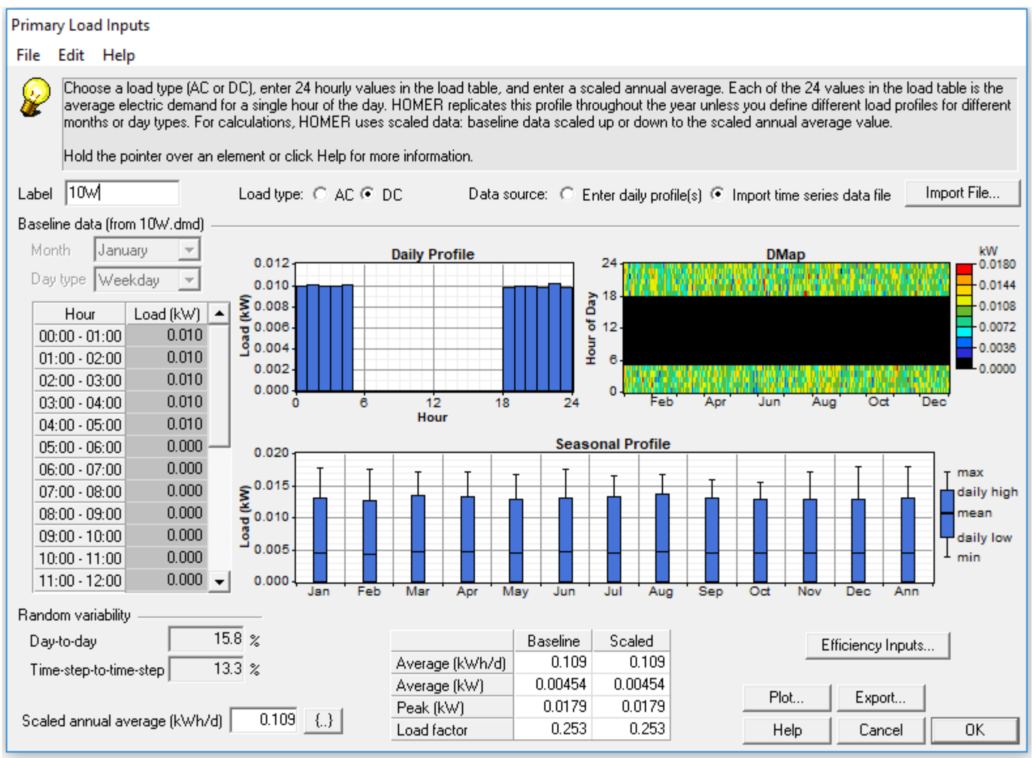

Figure 2. Load Input for the 10 W LED light.

Figure 2 shows the usage data for the 10 W LED light. The light is turned on from 6PM to 5AM which uses an average of 109 Wh/day with an 18 W peak load. For the solar resource, data is imported from the dataset published by Renee et al [10]. Mindanao cell 3553, which represents the solar data for Davao Region is used. The required lifetime of the system is at 25 years.

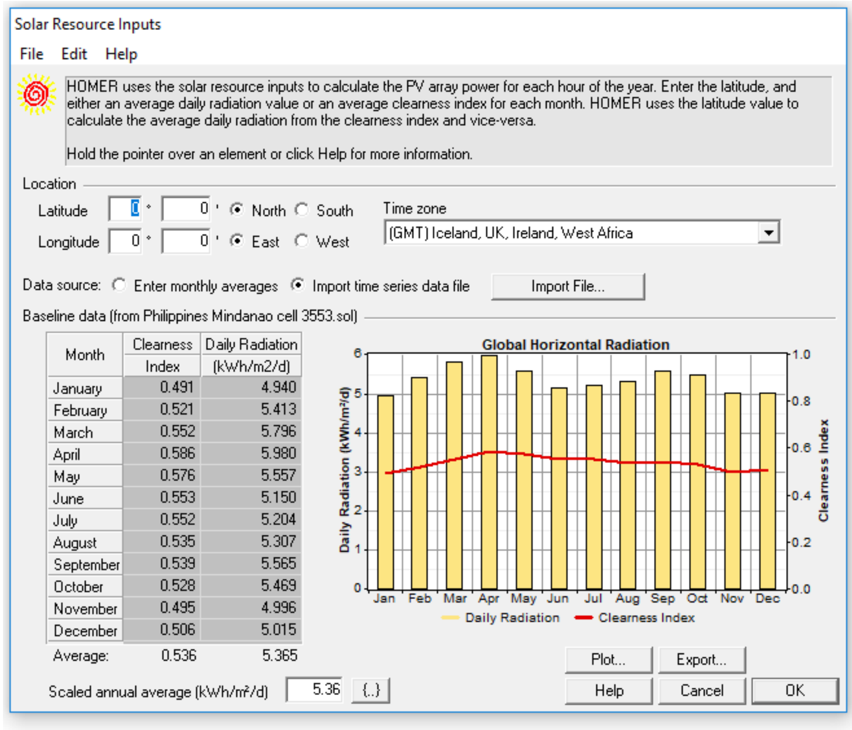

Figure 3. Solar resource data for Davao.

Given the parameters stated, we get the results of the simulation using the 10 W light as load. The results are shown on Table 3.

Table 3. Simulation results for the 10 W Streetlight.

PV (kW)	Solarmaster Battery 40/12	70/12	100/12	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Battery Life (yr)
0.05	2			$ 809	33	$ 1,232	2.422	4
0.1	2			$ 907	34	$ 1,343	2.641	4
0.05	3			$ 870	46	$ 1,457	2.865	4
0.05			1	$ 808	55	$ 1,517	2.982	2.3
0.05		2		$ 897	52	$ 1,557	3.061	4
0.1	3			$ 968	47	$ 1,569	3.084	4
0.1			1	$ 906	56	$ 1,628	3.201	2.3
0.1		2		$ 995	53	$ 1,668	3.28	4
0.05	4			$ 931	59	$ 1,683	3.308	4
0.1	4			$ 1,029	60	$ 1,794	3.527	4

The data is arranged based on lowest Cost of Energy (COE). The optimized solution is highlighted green. For the given design, a 50 W panel and two 40 Ah batteries are needed. The data also shows the use of a 100 Ah battery instead of two 40 Ah batteries which has comparable initial capital and more capacity. However, if the operating cost is considered and the Net Present Cost (NPC), it gives a higher value. This is because using only one battery constrains the system. If this single battery system breaks down, the system will not work. In addition, the lifetime throughput doubles if there are two batteries. Lifetime throughput is the amount of energy that cycles through the battery bank before it dies. Thus, it shows how the Homer simulation looks in design and economics of the system simulated.

Table 4. Simulation results for the 20 W Streetlight.

PV (kW)	**Solarmaster Battery**			**Initial Capital**	**Operating Cost ($/yr)**	**Total NPC**	**COE ($/kWh)**	**Battery Life (yr)**
	40/12	**70/12**	**100/12**					
0.1	3			$ 968	54	$ 1,659	1.631	3.5
0.1	4			$ 1,029	60	$ 1,794	1.764	4
0.1	5			$ 1,090	73	$ 2,019	1.985	4
0.1		3		$ 1,100	87	$ 2,212	2.175	3.5
0.1			1	$ 906	110	$ 2,314	2.277	1.2
0.1			2	$ 1,027	105	$ 2,364	2.324	2.3
0.1			3	$ 1,148	99	$ 2,413	2.373	3.5
0.15	3			$ 1,655	61	$ 2,440	2.399	3.5
0.1		4		$ 1,205	97	$ 2,444	2.403	4
0.2	3			$ 1,753	62	$ 2,552	2.509	3.5

For the 20 W load, the average consumption is 218 Wh/day, double that of the 10 W load, while the peak load is 33 W. The trend in the simulations is exhibited at the 20 W load as well. Since more energy is needed by the load, three 40 Ah batteries are needed in the optimal solution (highlighted green), with a 100 W solar panel. At this setup, the battery life is shorter because the lifetime throughput gets consumed faster by the larger load. This is also seen at a setup with one 100 Ah battery (highlighted yellow) wherein the life of the battery is now at 1.2 years. If the setup needs to have a battery life of 4 years, then an additional 40 Ah battery is to be added, which is the second scenario highlighted in orange. This would also incur cost implications that are not compensated with the longer battery life.

Finally, the average consumption of the 30 W load is 327 Wh/day, triple that of the 20 W load, while the peak is 48 W. The optimal setup (highlighted in green) uses a 150 W solar panel and four 40 Ah batteries. Again, adding one more battery increases the life (highlighted in orange), but would cost more. Moreover, using a larger capacity battery (highlighted in yellow) would have a larger operating cost.

Table 5. Simulation results for the 30 W Streetlight.

PV (kW)	Solarmaster Battery 40/12	70/12	100/12	Initial Capital	Operating Cost ($/yr)	Total NPC	COE ($/kWh)	Battery Life (yr)
0.15	4			$ 1,716	86	$ 2,811	1.842	3.1
0.15	5			$ 1,777	83	$ 2,837	1.86	3.9
0.2	4			$ 1,814	87	$ 2,922	1.915	3.1
0.2	5			$ 1,875	84	$ 2,949	1.933	3.9
0.1			4	$ 1,269	147	$ 3,148	2.063	3.1
0.15		4		$ 1,892	136	$ 3,631	2.38	3.1
0.15		5		$ 1,997	131	$ 3,677	2.41	3.9
0.2		4		$ 1,990	137	$ 3,742	2.453	3.1
0.2		5		$ 2,095	132	$ 3,788	2.483	3.9
0.15			2	$ 1,714	166	$ 3,832	2.511	1.5

VII. CONCLUSION

From the results, it is evident that using 40 Ah batteries in parallel provides a more reliable system since there are lesser replacements over the system's lifetime. This is due to the higher lifetime throughput from connecting more batteries in the string. Table 6 summarizes the optimal setup for the various streetlight designs investigated. From all the varying loads, the best design in terms of the COE is the 20 W light, costing only $ 1.63 per kilo-Watt hour. Although using a 10 W load would be the cheapest to invest, the cost per watt hour would be the highest among the three.

Table 6. Summary of optimal results by streetlight load.

LED Light	Usage (Wh/day)	PV (kW)	Solarmaster Battery 40/12	70/12	100/12	Initial Capital	Op. Cost ($/yr)	Total NPC	COE ($/kWh)	Batt. Life (yr)
10 W	109	0.05	2			$ 809	33	$ 1,232	2.422	4
20 W	218	0.1	3			$ 968	54	$ 1,659	1.631	3.5
30 W	327	0.15	4			$ 1,716	86	$ 2,811	1.842	3.1

All in all, solar streetlights provide light to communities that have no access to electricity. Being in a rural area, it is essential that these installations be the most affordable and reliable. The study presents the possibility of using a 10 W light to have cost savings in terms of initial capital and operating cost, while the 20 W light if better cost per Watt hour is preferred.

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